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# Early Middle Jurassic dinosaur footprints from Zizhou County, Shaanxi, China

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**Abstract** Four types of footprints of carnivorous dinosaurs have been found from the Yan'an Formation of early Middle Jurassic in Zizhou County, Shaanxi, China. From the top to bottom interval, the four types of footprints discovered at five layers in a 1.7 m thick stratum are as follows: 1) the large tridactyl footprints in the fifth layer (e, top) belong to *Zizhoupus wangi* ichnogen. et ichnosp. nov.; 2) the medium tridactyl footprints in the third and fourth layers (c–d) belong to *Changpeipus longweimaoensis* ichnosp. nov.; 3) small tridactyl or tetradactyl footprints in the second layer (b) belong to *Shensipus xiaoliheensis* ichnosp. nov. and 4) small tridactyl footprints in the first layer (a, bottom) belong to *Shensipus tungchuanensis*.

**Keywords** Zizhou, Shaanxi, Middle Jurassic, Yan'an Formation, dinosaur footprints

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## 1 Introduction

Shaanxi Province is the area where Teilhard de Chardin and C. C. Young (1929) found the first dinosaur track in China. Since then, more than 63 forms of dinosaur tracks in over 50 localities from the Upper Triassic to the Upper Cretaceous have been reported in China (Chen et al., 2006; Matsukawa et al., 1995; Zhen et al., 1996; Lockley et al., 2002, 2003, 2013; Kuang et al., 2013). There are many footprints on a single bedding plane in most regions like the bird and dinosaur tracks in Texas (Lee, 1997).

Four types of dinosaur footprints have been discovered in five layers in a 1.7 m thick stratum at one site from the Yan'an Formation (Middle Jurassic). The footprints are different from most dinosaur footprints found in China.

The tracksite is located in Longweimao village of Dianshi Town, Zizhou County, Shaanxi Province (N37°39′03.26″, E109°48′36.49″, Fig. 1) in China. The footprints were discovered by a local resident, Mr. Wang Jun, when he dug a cave dwelling near the village in June 2012. He recognized that the lower level footprints were smaller and the upper level ones were larger.

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The 1.7 m thick stratum in which the tracks are found can be divided into five layers (Fig. 2). The layers are 2–10 cm thick and composed by fine grained sandstone. The horizon of the rock belongs to lower Middle Jurassic of Yan'an Formation (Bureau of Geology and Mineral Resources of Shaanxi Province, 1989). Rock colors range from gray to gray-yellow. Some bedding plane structures, such as plant fragment imprints, ripple marks, mud cracks, worm trails and footprints can be observed on some bedding planes. The understratum consists of the pebble-bearing grit stone and the sedimentary structures include the cross bedding and oblique bedding with parallel bedding. It can be assigned to the Baotashan Sandstone of the lower portion of the early Middle Jurassic Yan'an Formation on the characteristic of lithology (Yang, 2008).

We have recognized 51 dinosaur footprints from a ~10 $m^2$ bedding plane in five levels (Layers a–e). Most tracks are scattered, except a few of which made up of two or more


Fig. 1 Locality map for Longweimao site
Abbreviations: K. Cretaceous; J. Jurassic; T. Triassic

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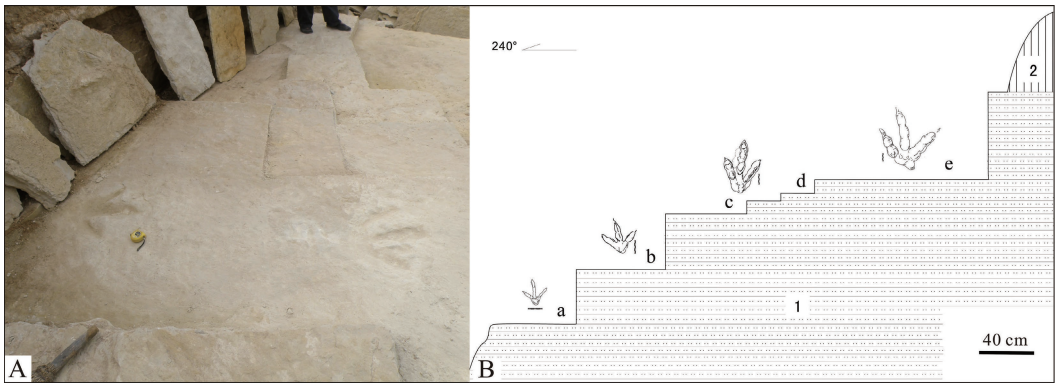


Fig. 2 Layer e (top) of Longweimao site (A) and section of dinosaur-footprints bearing strata (B)
1. the gray medium to fine-grained sandstone in the Yan'an Formation of early Middle Jurassic;
2. Quaternary loess

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footprints. The footprints can be grouped into four types, including: 1) large tridactyl tracks (Layer e); 2) medium tridactyl tracks (Layers c, d); 3) small tridactyl or tetradactyl tracks (Layer b) and 4) small tridactyl tracks (Layer a).

During 2013–2014, Xing et al. (2015) investigated other track sites and reported a new tracksites from the Zizhou area. They found some footprints and trackways of medium- to large-sized theropods which are similar to the ichnogenera *Kayentapus* and *Eubrontes*, and trackways of small bipedal ornithischians which are referred to as *Anomoepus* isp. In our paper, however, the tracks were discovered in multiple layers at one place and have a regular change of dinosaur footprint size through stratigraphic sequence, which is different from those described by Xing et al. (2015). Thus, it is necessary to make a further investigation.

**Abbreviations** NWUV, specimens number of Institute of Cenozoic Geology and Environment, Department of Geology, Northwest University.

## 2 Systematic descriptions

**Class Reptilia**

**Order Sauroschia**

**Suborder Theropoda Marsh, 1881**

**Ichnofamily Eubrontidae Lull, 1904**

***Zizhoupus* ichnogen. nov.**

**Type species** *Zizhoupus wangi* ichnogen. et ichnosp. nov.

**Etymology** *Zizhoupus* is named after the local region (Zizhou County) where the footprints were found. The species named in honor of Mr. Wang Jun, who found the footprints and contacted the authors to study and appraise them.

**Diagnosis** Large asymmetric bipedal walking tracks with tridactyl digit impressions. The claw marks at the distal end of digits and the oblong phalangeal pads are clear. The footprint is

more than 40 cm long. The track is longer than wide. The divarication angle between digits II and IV is 68° (average) and the pace is 156 cm long. The digit III is an inward rotation of the pes axis. The average divarication angle III-IV is twice as large as II-III.

### *Zizhoupus wangi* ichnogen. et ichnosp. nov.

(Fig. 3; Tables 1–2)

**Holotype** One large positive right track with tridactyl digit impressions, NWUV 1404 (field number: 12zz14).

**Paratypes** One large negative (concave) left track with tridactyl digit impressions, NWUV 1405 (field number: 12zz15).

**Referred materials** One half of a large positive (convex) track with tridactyl digit impressions, NWUV 1406 (field number: C 9); two negative footprints, field numbers: C 45, 46 (Fig. 2A, preserved on-the-spot at Longweimao field site).

**Horizon and locality** Layer e of Longweimao site, Zizhou County, Shaanxi Province, Yan'an Formation in early Middle Jurassic.

**Diagnosis** Same as the diagnose of the ichnogenus above.

**Description** Three scattered footprints of two positive (convex) , a negative (concave) and two negative (concave) footprints on site were separately collected from (or preserved on) the top of the section, Layer e (Fig. 2). The size and shape of NWUV 1404 (Fig. 3) are very close to those of NWUV 1405. The digit III is the longest, the divarication angles between digits II, III and IV are II 21° III 46° IV. The footprint is 40 cm long and 36.8 cm wide. Its aspect ratio is 1.09. The two negative (concave) footprints (C 45, 46 ) preserved on-the-spot consist of a trackway pace (Fig. 2B). The pace is 156 cm long and the sizes and shapes of the footprints are consistent with NWUV 1404–1406 (Table 1). The middle digit (III) slant is slightly outward. The direction of the right claw of C 45 is about 250°, and the left claw of C 46 is about 240°.

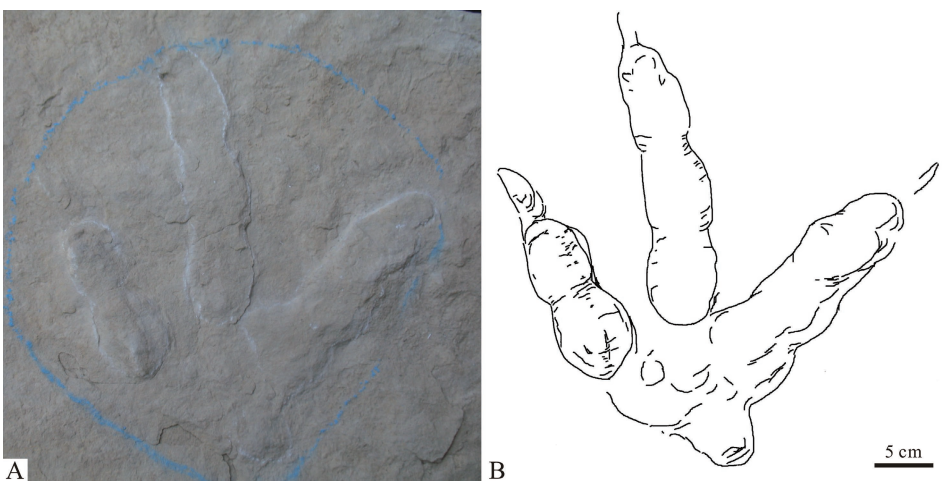


Fig. 3 Photograph (A) and line drawing (B) of *Zhizhoupus wangi* ichnogen. et ichnosp. nov. (NWUV 1404)

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**Table 1 Measurements of footprints and trackway of *Zhizhoupus wangi* ichnogen. et ichnosp. nov.** (mm)

| Track number | Footprint | | | Digit length | | | Divarication angle | | |
|---|---|---|---|---|---|---|---|---|---|
| | Length | Width | L/W | II | III | IV | II-III | III-IV | II-IV |
| NWUV 1404 | 400 | 368 | 1.09 | 204 | 271 | 232 | 21° | 46° | 67° |
| NWUV 1405 | 420 | 360 | 1.17 | 220 | 275 | 220 | 21° | 43° | 64° |
| NWUV 1406 | 490 | 380 | 1.29 | 210 | 310 | 225 | 22° | 50° | 72° |
| Average | 437 | 369 | 1.18 | 211 | 285 | 226 | 21° | 46° | 68° |

**Discussion** Lockley et al. (2003, 2013) reviewed Mesozoic dinosaur footprint of China and renamed some ichnotaxonomy: *Youngichnus xiyangensis* to *Eubrontes xiyangensis*, *Megaichnites jizhaoshiensis* to *Kayentapus jizhaoshiensis*, *Jinlijingpus nianpanshanensis* to *Eubrontes nianpanshanensis*, and *Chonglongpus hei* to *Gigandipus hei*. The large footprints of Carnosauria previously found in China mainly include *E. platypus* from the Jurassic, *E. xiyangensis*, *Changpeipus carbonicus*, *K. jizhaoshiensis*, *E. nianpanshanensis*, *G. hei* (Zhen et al., 1996; Yang and Yang, 1987), *Lufengopus dongi* ( Lü et al., 2006) and *Chapus lockleyi* from Lower Cretaceous (Li et al., 2006). Compared with those above, *Zizhoupus* footprints differs from *G. hei* on bipedal three-toed. It differs from the bipedal three-toed *Kayentapus*, *Changpeipus* and *Eubrontes* on the larger size (length greater than 40 cm), the larger divergences angle between digits (more than 60° between II-IV), and the oblong phalangeal pad. It also differs from *E. platypus* and *E. xiyangensis* on a narrow foot posterior. *Zizhoupus* footprint is easily distinguished from *Chapus* because of the smaller divarications between digits, shorter pace and the paw tracks of *Chapus*, and late stratigraphic age ($K_1$, Lower Cretaceous). The differences are shown in detail in Table 2.

HI3, a tridactyl footprints of bipedal dinosaurs from the Huo tracksite, is similar to *Zizhoupus*, but a little smaller (Xing et al., 2015).

**Table 2 Comparison between *Zhizhoupus wangi* ichnogen. et ichnosp. nov. and some large footprints of Carnosauria in China** (mm)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| FL | 400 | 270 | 265 | 336 | 385 | 376 | 490 | 582 |
| FW | 368 | 240 | 175 | 234 | 280 | 380 | 370 | 426 |
| FL/FW | 1.09 | 1.13 | 1.51 | 1.44 | 1.38 | 0.99 | 1.32 | 1.37 |
| P | 1560 | 1050 | 1125 | | 1150 | 1010 | 1200 | 1350 |
| P/FL | 3.90 | 3.89 | 4.25 | | 2.99 | 2.69 | 2.45 | 2.32 |
| II-IV | 67º | 37º | 21º | 46º | 50º | 50º | 37º | 48º |
| Heel | shrink | broad | broad | shrink | shrink | shrink | shrink | shrink |
| Age | $J_2^1$ | $J_1$ | $J_1$ | $J_{1\text{-}2\text{-}3}$ | $J_2$ | $J_2$ | $J_2$ | $K_1$ |

Notes: 1. *Zizhoupus wangi*; 2. *Eubrontes platypus*; 3. *E. xiyangensis*; 4. *Changpeipus carbonicus*; 5. *Kayentapus jizhaoshiensis*; 6. *E. nianpanshanensis*; 7. *Gigandipus hei*; 8. *Chapus lockleyi*; FL. footprints length; FW. footprints width; P. pace; II-IV. divarication II-IV; $J_1$. Lower Jurassic; $J_{1\text{-}2\text{-}3}$. Lower, Middle, and Upper Jurassic; $J_2$. mid-Jurassic; $J_2^1$. Lower of mid-Jurassic; $K_1$. Lower Cretaceous. Citations: Zhen et al., 1996 (2–7); Li et al., 2006 (8).

### *Changpeipus longweimaoensis* ichnosp. nov.

(Fig. 4; Table 3)

**Holotype** One medium-sized positive right track with tridactyl digit impressions, NWUV 1407 (field number: 12zz01).

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**Paratypes** One medium-sized positive right track with tridactyl digit impressions, NWUV 1408 (field number: 12zz13).

**Referred materials** Two negative and one positive tracks with tridactyl digit impressions, field numbers: C 5, 6, 66 (preserved on-the-spot in Longweimao Field site).

**Horizon and locality** Layers c–d of Longweimao site, Zizhou County, Shaanxi Province, Yan'an Formation in early Middle Jurassic.

**Diagnosis** Asymmetric bipedal walking tracks with tridactyl digit impressions. The claw marks at the distal end of digits and the oblong phalangeal pads are clear. The footprints are 23.4–32.4 cm long (28.1 cm on average). The footprint is longer than wide. The divarication angle II-IV is 55º–64º (59º on average).

**Etymology** The species named *longweimaoensis* is after the name of the local region (Longweimao village) where the footprints were found.

**Description** The holotype (NWUV 1407, Fig. 4) and the paratypes are all scattered positive (convex) footprints on the fine grained sandstone. They are medium-sized theropod dinosaur footprints with tridactyl digits and the digit II is the shortest. The oblong phalangeal pads are clear. The holotype is well preserved in comparison with the others. The measurements are shown in Table 3.

**Discussion** According to Zhen et al. (1996), it is generally believed that *Changpeipus* includes medium-sized footprints (footprint length of *C. carbonicus* is 29.2–38.3 cm) with the narrow posterior footprints and large angles between digits. The five tracks (NWUV 1407, 1408, C 5, 6, 66) described here are medium-sized with bipedal tridactyl digits, having large angle between digits and short II digit. Footprints are 23.4–32.4 cm in length and 17.5–27.9 cm

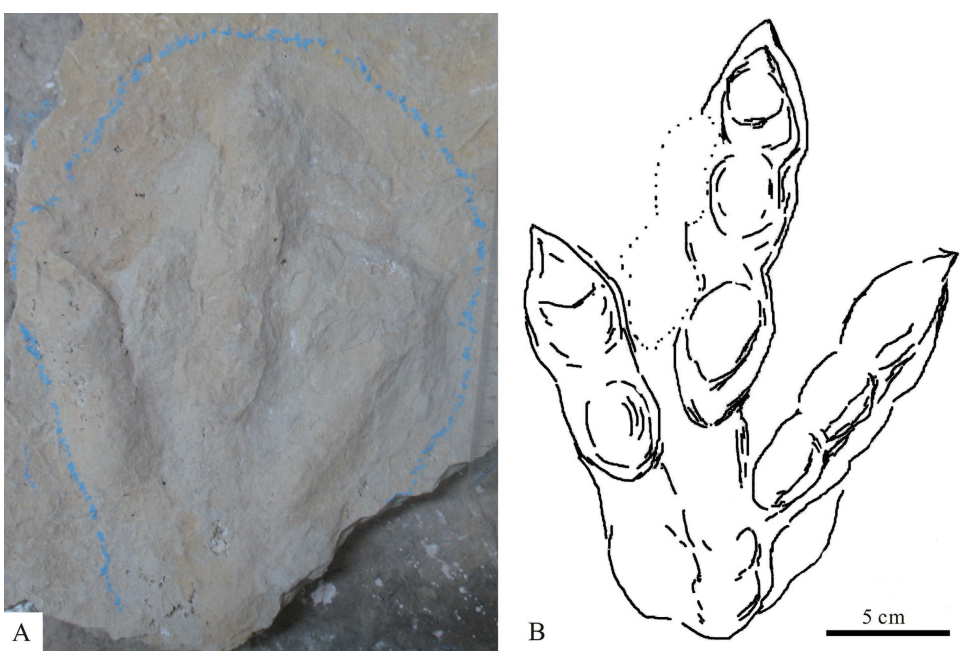


Fig. 4 Photograph (A) and line drawing (B) of *Changpeipus longweimaoensis* ichnosp. nov. (NWUV 1407)

**Table 3 Measurements of footprints and trackway of *Changpeipus longweimaoensis* ichnosp. nov.** (mm)

| Track number | Footprint | | | Digit length | | | Divarication angle | | |
|---|---|---|---|---|---|---|---|---|---|
| | Length | Width | L/W | II | III | IV | II-III | III-IV | II-IV |
| C 5 | 324 | 279 | 1.16 | 234 | 254 | 215 | 25° | 36° | 61° |
| C 6 | 234 | 175 | 1.34 | 141 | 189 | 135 | 27° | 28° | 55° |
| C 66 | 309 | 257 | 1.20 | 124 | 179 | 91 | 23° | 41° | 64° |
| NWUV 1407 | 254 | 180 | 1.41 | 114 | 171 | 134 | 31° | 30° | 61° |
| NWUV 1408 | 286 | 271 | 1.06 | 146 | 206 | 203 | 22° | 34° | 56° |
| Average | 281 | 232 | 1.23 | 152 | 200 | 156 | 26° | 34° | 59° |

in width. The angle between digits II and IV is 55º–64º (average 59º). All of these features obviously belong to footprints of *Changpeipus* (Young, 1960, 1979; Zhen et al., 1996; Lü et al., 2007; Xing et al., 2009a).

All fossils of *Changpeipus* have been collected from the Jurassic formations, including *C. carbonicus* footprint from the Early, Middle and Upper Jurassic, *C. xuiana* footprint from Middle Jurassic and the tracks in the paper from the lower part of Middle Jurassic.

The differences between the tracks from Longweimao and the footprints of other species of *Changpeipus* are shown as follow: the Longweimao footprints do not include a tarsal impression appearing at the back of the footprint as in *C. xuiana* (Lü et al., 2007). Longweimao footprints with an length-width ratio range 1.06–1.41 (average 1.23) differ from *C. xuiana* (average 1.9) and *C. carbonicus* (average 1.58) (Zhen et al., 1996). The cf. *Changpeipus* isp. from Lower Jurassic in Xinjiang is much shorter and wider with the length-width ratio of only 0.44 (Young, 1960, 1979; Zhen et al., 1996; Xing et al., 2014). Differences between *C. longweimaoensis* and *C. pareschequier* are as follows: the divarications between digits of *C. longweimaoensis* (II 26° III 34° IV) are not as same as those of *C. pareschequier* (II 28° III 28° IV); the phalangeal pad formula of *C. longweimaoensis* is x-2-3-4-x but x-2-3-2-x in *C. pareschequier*. Longweimao footprints are not like the *C. pareschequier* footprints with the round metatarsophalangeal pad and the subequal divarication angle II-III and III-IV (Xing et al., 2009a). Longweimao footprints from the mid-Jurassic is younger than *C. pareschequie* from the Lower Jurassic in Yunnan (Xing et al., 2009a). As a result, we classify these tracks as a new species: *Changpeipus longweimaoensis* ichnosp. nov.

**Coelurosauria indet.**

**Ichnogenus *Shensipus* Young, 1966**

***Shensipus xiaoliheensis* ichnosp. nov.**

(Fig. 5; Table 4)

**Holotype** One piece with two negative tracks with tridactyl digit impressions, NWUV 1409 (field number: 12zz03).

**Paratypes** One piece with two positive tetradactyl, NWUV 1410 (field number: 12zz02).

**Referred materials** 11 pieces with 24 small tridactyl digit impressions (five pieces stored in the Department of Geology, Northwest University in NWUV 1411–1415, and the others on-the-spot of observations, C1–4, 8, 48, 64).

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**Horizon and locality** Layer b of Longweimao site, Zizhou County, Shaanxi Province, Yan'an Formation in early Middle Jurassic.

**Etymology** The species name *xiaoliheensis* is after the name of the local region (Xiaolihe River Basin) where the footprints were found.

**Diagnosis** Small theropod dinosaur footprints, tridactyl or tetradactyl digits. Pes functionally tridactyl with medially-directed hallux sometimes imprinted. The digit III is the longest, and the digit IV is longer than the digit II. The phalangeal pads are unclear. The footprint lengths are range from 9.6 to 21.3 cm (13.8 cm on average). The aspect ratio is 1.11, The average divarication angle II-IV is 74°.

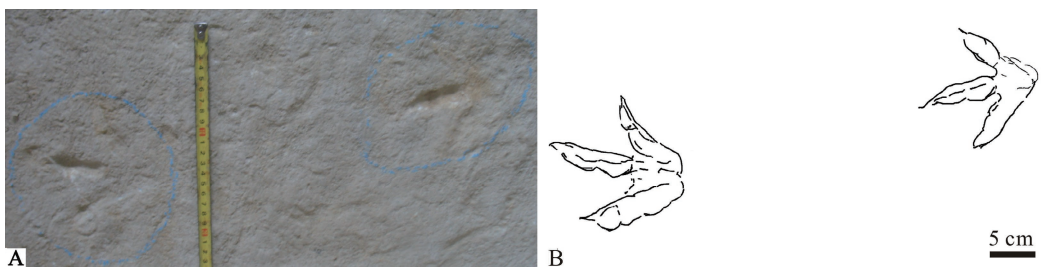


Fig. 5 Photograph (A) and line drawing (B) of *Shensipus xiaoliheensis* ichnosp. nov. (NWUV 1409)

**Description** The holotype (NWUV 1409) and paratype (NWUV 1410) are preserved in the fine grained sandstone (Fig. 5). The holotype has tridactyl digits, and digit III is the longest with two pads. The digit III and IV are slightly longer with three or four pads. The angle between digits II and III is slightly smaller than that between III and IV. The paratype is positive (convex) of four digits with a small hallux imprint ( I? ). The digit I is 3 cm long with claw track at the distal end. It is outspread to digit IV in the opposite direction. In other words, the angle between digits I and IV is close to 180°. The digit II, III and IV are almost the same in size and shape. In referred materials (NWUV 1411–1415), only NWUV 1415 has an unclear hallux imprint. These footprints are all located in the Layer b (Fig. 2). The measurement data are shown in Table 4.

**Discussion** Compared with those dinosaur footprints found in China, the sizes and shapes of the specimens collected in Layer b of Longweimao site are much closer to *Shensipus*, so we classified them into the genus. These footprints belong to a new species in *Shensipus* according to the follows: 1) the range of the length variation of *S. xiaoliheensis* is between 10–20 cm; 2) its shape is similar to the small theropod dinosaurs such as *Shensipus*, but has different angle variation between digits. The average divarication angle II-IV of *Shensipus* in Zizhou is 74° (Table 4) which less than 90° of *S. tungchuanensis* from Tongchuan (Young, 1966; Zhen et al., 1996) and 102° of *S. tungchuanensis* in this paper (Table 5); 3) it has four-toed imprinting (hallux) sometimes, which could not be seen in *S. tungchuanensis*. 4) since only in a few footprints the hallux can be seen, most of the others are similar to *Shensipus* footprints in shape and size, so here we classify them as a new species: *S. xiaoliheensis* ichnosp. nov.

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**Table 4 Measurements of footprints and trackway of *Shensipus xiaoliheensis* ichnosp. nov.** (mm)

| Track number | Footprint | | | Digit length | | | | Divarication | | | | Pace |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L | W | L/W | I | II | III | IV | I-II | II-III | III-IV | II-IV | |
| C 1 | 103 | 134 | 0.77 | | 60 | 65 | 55 | | 45° | 52° | 97° | |
| C 2 | 130 | 154 | 0.84 | | 72 | 98 | 77 | | 45° | 52° | 97° | 295 |
| C 3 | | | | | | 151 | 92 | | | 31 | | |
| C 4 | 186 | 138 | 1.35 | | 84 | 138 | 114 | | 23° | 25° | 48° | |
| C 8a | 123 | 89 | 1.38 | | 42 | 85 | 50 | | 28° | 35° | 63° | |
| C 8b | 127 | 139 | 0.91 | | 77 | 96 | 58 | | 32° | 35° | 67° | 308 |
| C 8c | 127 | 112 | 1.13 | | 58 | 81 | 46 | | 26° | 42° | 68° | 296 |
| C 8d | 142 | | | | | 104 | 73 | | | 33° | | |
| C 8e | 142 | | | | | 108 | 69 | | | 60° | | |
| C 8f | 96 | | | | | 69 | 50 | | | 33° | | |
| C 8g | 96 | | | | | 58 | 54 | | | 60° | | |
| C 8h | 119 | 123 | 0.97 | | 50 | 92 | 54 | | 34° | 45° | 79° | |
| C 8i | 96 | 89 | 1.08 | | 46 | 65 | 50 | | 25° | 42° | 67° | |
| C 8j | 119 | | | | 50 | 89 | | | 29° | | | |
| C 48 | 193 | 157 | 1.23 | | 77 | 146 | 91 | | 22° | 31° | 53° | |
| C 64 | 172 | 169 | 1.02 | | 78 | 159 | 72 | | 37° | 38° | 75° | |
| NWUV 1409a | 112 | 116 | 0.97 | | 52 | 76 | 52 | | 41° | 47° | 88° | |
| NWUV 1409b | 128 | 124 | 1.03 | | 60 | 80 | 60 | | 32° | 36° | 68° | 340 |
| NWUV 1410a | 107 | 81 | 1.32 | 30 | 58 | 81 | 56 | 62° | 38° | 48° | 86° | |
| NWUV 1410b | 107 | 81 | 1.32 | 30 | 77 | 81 | 77 | 80° | 38° | 42° | 80° | 364 |
| NWUV 1411a | | 175 | | | 111 | | 100 | | 20° | 37° | 57° | |
| NWUV 1411b | | 186 | | | 89 | 97 | 83 | | 39° | 55° | 94° | |
| NWUV 1411c | | | | | | 147 | 94 | | | 46° | | |
| NWUV 1412a | 182 | 142 | 1.28 | | 80 | 147 | 93 | | 22° | 33° | 55° | |
| NWUV 1412b | 213 | 178 | 1.20 | | 89 | 133 | 98 | | 28° | 32° | 60° | 444 |
| NWUV 1414 | 189 | 180 | 1.05 | | 118 | 156 | 164 | | 20° | 38° | 58° | |
| NWUV 1415a | 156 | | | | 69 | 106 | | | 51° | | | |
| NWUV 1415b | | 200 | | | 81 | 119 | 75 | | 48° | 65° | 113° | |
| Average | 138 | 138 | 1.11 | 30 | 72 | 105 | 75 | 71° | 33° | 42° | 74° | 341 |

Xing et al. (2015) re-named *Shensipus tungchuanensis* Young, 1966 to Ichnogenus *Anomoepus* Hitchcock, 1848: *Anomoepus tungchuanensis* (Young, 1966) comb. nov. They inferred that the tracks belong to ichnogenus *Anomoepus* as these tracks closely resemble those reported by Li et al. (2012:fig. 12B) and others described from the Huo tracksite. Xing et al. (2015) considered *S. tungchuanensis* as a subjective junior synonym of *Anomoepus sensu lato* and thus proposed the new combination *A. tungchuanensis*.

Xing et al. (2015) declared that "All these characteristics, notably the wide digit divarication, length/width ratio, **short step**, and inward rotation, are characteristic of *Anomoepus* (Lockley and Gierlinski, 2006)."

The actual quote is "The **long step** of *A. cuneatus* (pes length: step ratio of 1:5.6 to 1:8 and pes width: step ratio of 1:7.7 to 1:10.7) described by Lull (1953) from the Newark Supergroup is also similar to the ratio recorded for *Anomoepus* from the Lisbon Valley Oilfield site (about 1:8), and the exceptional ratio of between 1:18.3 and 1:19.9 recorded for *Hopiichnus*." (Lockley and Gierlinski, 2006, p:182)

Lockley et al. (2013) considered that *Shensipus* is a distinctive and possibly valid

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ichnotaxon of all affinity. We agree with this view and thus kept the original classification (Young, 1966) in our study.

### *Shensipus tungchuanensis* Young, 1966

(Fig. 6; Table 5)

**Materials** Four pieces of small scattered tridactyl footprints, NWUV 1416 (field number: 12zz23). C 55, 69, 70 (on-the-spot to observation). One piece about 1 m×0.8 m with nine small tridactyl footprints, field number: C 34 (on-the-spot of observation). Footprints are from the Layer a (bottom) of the section.

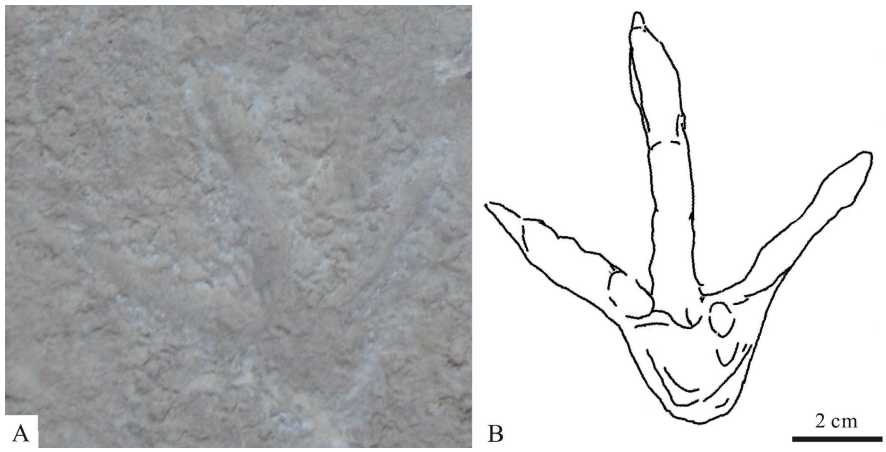


Fig. 6 Photograph (A) and line drawing (B) of *Shensipus tungchuanensis* (NWUV 1416)

**Table 5 Measurements of footprints and trackway of *Shensipus tungchuanensis*** (mm)

| Track number | Footprint | | | Digit length | | | Divarication angle | | | Pace |
|---|---|---|---|---|---|---|---|---|---|---|
| | Length | Width | L/W | II | III | IV | II-III | III-IV | II-IV | |
| C 34a | 71 | 93 | 0.76 | 43 | 57 | 43 | 47° | 85° | 132 | |
| C 34b | 71 | 93 | 0.76 | 43 | 57 | 50 | 58° | 60° | 118° | 350 |
| C 34c | 86 | 100 | 0.86 | 50 | 64 | 43 | 45° | 60° | 105° | |
| C 34d | 79 | 100 | 0.79 | 43 | 64 | 43 | 47° | 60° | 107° | 293 |
| C 34e | 86 | 100 | 0.86 | 50 | 64 | 43 | 40° | 58° | 98° | 407 |
| C 34f | 71 | 79 | 0.90 | 36 | 50 | 36 | 44° | 49° | 93° | |
| C 34g | 50 | 79 | 0.63 | 29 | 36 | 29 | 51° | 55° | 106° | 179 |
| C 34h | 64 | 79 | 0.81 | 29 | 43 | 29 | 43° | 47° | 90° | 171 |
| C 55 | 80 | 91 | 0.88 | 55 | 68 | 61 | 35° | 44° | 79° | |
| C 69 | 82 | 134 | 0.61 | 63 | 75 | 59 | 62° | 67° | 129° | |
| C 70 | 101 | 96 | 1.05 | 62 | 70 | 77 | 37° | 39° | 76° | |
| NWUV 1416 | 94 | 87 | 1.08 | 44 | 72 | 48 | 45° | 47° | 92° | |
| Average | 78 | 94 | 0.83 | 46 | 60 | 47 | 46° | 56° | 102° | 280 |

**Description** C 34 is a large slab with 3 rows of 9 negative footprints. NWUV 1416 is a positive (convex) small tridactyl footprint. The phalangal pads are unclear and the digits are slender. The heel is small (Fig. 6). The foot is 9.4 cm long and the angle between digit II and IV is 92°. The measured data are shown in Table 5. The others (C 55, 69, 70) are scattered

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pieces with one footprint on each of them. According to the 12 footprints measured (Table 5), the footprints are 5–10.1 cm long (7.8 cm on average) and 7.9–13.4 cm wide (9.4 cm on average). The center digit (III) is the longest, and the digit II is the shortest.

**Discussion** The *Shensipus tungchuanensis* footprint is characterized by bipedal tridactyl and each digit is very slender. The angle II-III and III-IV is large (II 32° III 58° IV). The footprint is 9–10 cm long and the pace is 9.7 cm long from Middle Jurassic (Young, 1966; Zhen et al., 1996). The characteristics described above include that the footprints are less than 10 cm long, with a slender claw digit and the angles between digits II-IV greater than 90°, quite consistent with *S. tungchuanensis* footprint from the Jurassic. Therefore, we classified these footprints into the species: *S. tungchuanensis*.

## 3 Discussion

**The body length, height and gait of the track maker** Predecessor results indicate that the hip height is equivalent to its leg length, about 4 times foot length in mammalia (Alexander, 1976), and the body length is about 2.63–3.5 times as the hip height (Xing et al., 2009b; Li et al., 2006). Based on the measurements of newly discovered dinosaur footprints, the calculated results show that the smallest dinosaur footprint of *Shensipus tungchuanensis* represents an animal with a hip height 31.2 cm and is 0.8–1.1 m in body length. The larger track maker of *S. xiaoliheensis* ichnosp. nov., is about 55.2 cm high and 1.5–1.9 m long. The track maker of *Changpeipus longweimaoensis* ichnosp. nov. is 1.1 m high and 3–3.9 m long, being a medium-sized dinosaur. The largest footprint, *Zizhoupus wangi* ichnogen. et ichnosp. nov., is a representative of a large dinosaur with 4.6–6.1 m long and 1.75 m of hip height.

**Geological age** The thickness of the Middle Jurassic strata in the Yan'an to Fugu area of northern Shaanxi Province is about 200–300 m (Bureau of Geology and Mineral Resources of Shaanxi Province, 1989). The Yan'an Formation near the Dalihe River is about 220 m thick (Yang, 2008). According to the latest International Stratigraphic Chart, the Middle Jurassic extends around 174.1–163.5 Ma (International Commission on Stratigraphy, 2015), a time span of about 10.6 Ma. The estimated deposit rate in research area is about 100,000 years per 2.1 m on average. The section of Longweimao site spans less than 100,000 years for the 1.7 m thick stratum.

Many dinosaur footprints discovered at the sites are from one layer at the one place. But in Longweimao tracksite, the dinosaur footprints are discovered in 5 layers at the one place, and the sizes of dinosaur footprints are increasing upward. The tracks discovered in the multi-layers at one place with a regular change of dinosaur footprint size through the stratigraphic sequence are rare. This phenomenon has not been reported in previous studies yet.

The case of the adjacent area reported by Xing et al. (2015) is quite different from those discovered in our study. Such difference may be due to different investigated layers. We described the same place within a distance of 1.7 m and observed five different layers. However, the work of Xing et al. (2015) is based on the single layer from the other locations. This difference may not only result in the same or similar features but also completely cause

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the different features. This situation is normal and need more evidence to further verification. After all, the continental strata change a lot vertically and/or horizontally.

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# 陕西子洲中侏罗世早期恐龙足迹初步研究

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**摘要**：陕西子洲县中侏罗统延安组砂岩中，同一地点共厚约1.7 m的5个层面发现4种食肉类恐龙足迹，自上而下分别为：1) 第5层面大型三趾型足迹，实雷龙足迹科王氏子洲足迹(新遗迹属、新遗迹种) *Zizhoupus wangi* ichnogen. et ichnosp. nov.; 2) 第4和第3层面中型三趾型足迹，实雷龙足迹科龙尾峁张北足迹(新遗迹种) *Changpeipus longweimaoensis* inchnosp. nov.; 3) 第2层面小型三趾或四趾型足迹，虚骨龙类小理河陕西足迹(新遗迹种) *Shensipus xiaoliheensis* inchnosp. nov.; 4) 第1层面小型三趾型足迹，虚骨龙类的铜川陕西足迹*Shensipus tungchuanensis*。

**关键词**：陕西子洲，中侏罗统，延安组，恐龙足迹

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